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Wind energy development in the world, Europe and Poland from 1995 to 2009; current status and future perspectives

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ABSTRACT

In this article we present directions of wind energy development in the world, Europe and Poland in the years 1995–2009, current status and future perspectives of wind energy. At the end of 2009 the total capacity of wind turbines installed in the world accounted for nearly 160 GW. According to recent guidelines for the countries of the European Union production of electricity from wind will amount to 20% of energy demand by 2020. On other continents situation is similar, what makes wind energy rapidly growing sector of economy.

Contents

1. Introduction

As is clear from surviving documents (Code of Hammurabi from 1750 BC), the oldest wind facilities were built more than 4000 years ago. Wind power was used, inter alia, by windmills and sailing ships, for water pumping and irrigation, for grinding grain and sawing rice.

In Europe, the oldest mention of windmills dates back to the ninth century in England and the eleventh century in France (on the Polish lands in the thirteenth century).

Interest in renewable energy resources has increased significantly following the energy crisis of 1973. Since then there has been installed more than 120 GW of new capacity in more than 50,000

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Table 1
Wind energy potential in the world [1].

Continent	Gross potential, TWh/year	Technical potential, TWh/year
Africa	106,000	10,600
Australia and Oceania	30,000	3000
North America	139,000	14,000
South America	54,000	5400
East Europe	106,000	10,600
West Europe	31,400	4800
Asia	32,000	4900
The World total	498,000	53,000

wind turbines over the world. Wind energy is now one of the fastest growing sectors of modern economy.

2. Global wind energy resources

The global potential of wind energy defines a series of studies. In [1] it was estimated at 500,000 TWh/year. It has been determined (Table 1) for areas with average wind speeds over 5 m/s at a height of 10 m above ground level. This value was then reduced by 90% due to the use of land under cultivation, for residential purposes and others. A more conservative estimate gives [2], indicating that potential at 20,000 TWh/year.

Very promising for the development of wind energy are sea areas. For example, the [3] identifies the technical potential of see areas for Europe, after the adoption of environmental constraints (Nature 2000). Calculations were made for the height of 80 m above the sea level. It was assumed that 10% of the distance from 10 to 50 km from the coast can be used for wind energy. For larger distances this share is 25%. Values of these factors are mainly due to constraints relating to the maritime security. Obtained value is 3500 TWh/year in the perspective of 2030.

Due to the EIA data [4], the world total net electricity consumption in 2006 was 16.4 PWh. The comparison above data shows that wind energy can cover, theoretically, the world's consumption of electricity. Of course, due to the growing energy needs, regional differentiation, geographical and technical restrictions its not so obvious, but wind energy can play significant role in world's energy balance.

3. Development of wind energy in the world from 1995 to 2009

3.1. Introduction

Using the information published in this field by competent sources [5–43] there are summarized in table's data concerning wind energy development at the various continents. Because of the unequal allocation of countries in different data sources, the geographic distribution used by the UN [44] and the WEC (World Energy Council) [45] was adopted. For the analysis there were assumed successively following continents: Africa, America, Australia and Oceania, Asia and Europe. Detailed data for each continent are presented in Tables 2–6. Power values in all cases are given in MW.

3.2. Africa

Africa has considerable potential for wind power development, but mainly in southern and northern parts of the continent. In the sub-Saharan countries wind has rather low speed. It should be noted, however, that wind energy has been used here very widely for a long time for purposes like water pumping, irrigation, household use, and for livestock in wind turbines using mainly low-speed winds.

The capacity of wind turbines installed in African countries is shown in Table 2. The use of wind energy in Africa firstly became in the countries of the northern part of the continent, the most privileged in terms of wind conditions: Egypt, Morocco and Tunisia. In 2000 on the continent installed 135 MW, and the 132 MW (98%) in these three countries. In 2008 it was 593 MW and 578 MW respectively (97%), and a year later 752 MW and 737 MW (98%). So they are still leaders in the development and promotion of wind energy in Africa. However, despite the large increase in installed capacity, the value of 464 MW in 2007 for the whole continent was below forecasts indicating the possibility of achieving 620–1000 MW [36].

Zapis fonetyczny

3.3. America

The pioneer of industrial use of wind power is the United States. The first wind farms were built in 1981 in California. In 1985 the installed capacity in wind energy in the United States amounted to more than 1 GW. However, after initial rapid growth in the 90s its dynamics slackened (Table 3). As a result, in 1997 the U.S. gave way to Germany, as a leader of the largest capacity installed in wind turbines.

In 2006 there have been mounted in the USA 1800 power plants with total capacity of 2454 MW, which gives an average of 1.36 MW/turbine. In 2007, 3232 plants were built there (including the replacement of old plants) with a capacity of 5333 MW, giving an average power of 1.65 MW/turbine. In 2008 the U.S. installed a record number of 5105 turbines with a total capacity of 8558 MW, which gives an average power of 1.68 MW/turbine. In 2009 it was 5760 units and 9922 MW respectively, giving an average power of 1.72 MW. With this investment, the U.S.A. once again became the world leader in terms of operating wind turbines capacity, increasing it in 2008 by 42% over the previous year. In 2009 there was installed almost 10 GW of new capacity, what gave a similar, almost 40% growth.

By contrast, in the southern part of the continent development of wind power was weaker. However, in recent years there has been noticed an acceleration, but not as rapid as in the U.S. After almost three years of stagnation, for a lot of investments (317 MW), nearly five times increased wind capacity installed in Mexico. Disputes growth was also in Costa Rica (an increase of 49 MW). In 2008, only Brazil recorded an increase of 94 MW capacity in five new farms, mainly in northern and eastern parts of the country. It gave to Brazil a leadership position in installed capacity of 339 MW. With new installations of 261 MW (77% increase y/y) in 2009 it remained on the leading place on the southern part of the continent.

3.4. Australia and Oceania

Due to the nature of this continent, it is clear that the greatest potential for wind energy development has Australia. In the 1980s and 1990s several states engaged in systematic wind speed monitoring, the results of which are publicly available [7]. Thanks to good wind conditions and Government's Renewable Energy Target, it shifted into a power value of over 1.8 GW from 2.3 GW of working across the continent in 2009. Large investments were also made in recent years in New Zealand.

It should also be noted that in area of small islands in the Pacific is still also developing this branch of power. Effectively compete with it, however, solar energy and wind-aided autonomous systems supported by diesel generators and solar wind very popular in islands.

Table 2
Wind energy in Africa.

No.	New power Total	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
1	Egypt		0	0	0	30	33	0	0	30	47	0	85	80	55	40
		5	5	5	5	35	68	68	68	98	145	145	230	310	390	430
2	Morocco					14	40	0	0	0	0	10	58	3	10	129
					0	14	54	54	54	54	54	64	122	124	134	253
3	Tunisia						10	0	0	10	0	0	0	0	34	0
						0	10	10	10	20	20	20	20	20	54	54
4	Nigeria									1	0	0	0	0	0	0
									1	2	2	2	2	2	2	2
5	RSA									3	0	0	0	0	5	0
									0	3	3	3	3	3	8	8
6	Cape	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Verde	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
7	Algeria											0	0	0	0	0
											1	1	1	1	1	1
8	Eritrea										1	0	0	0	0	0
										0	1	1	1	1	1	1
	TOTAL	0	0	0	0	44	83	0	0	44	47	10	143	83	104	169
		8	8	8	8	52	135	135	136	180	229	239	382	464	593	752

Table 3
Wind energy in America.

No.	New power Total	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
1	USA	41	24	29	530	324	30	1750	410	1687	370	2431	2454	5244	8358	9922
		1770	1677	1611	2141	2465	2495	4245	4655	6361	6740	9181	11,603	16,879	25,170	35,159
2	Canada	0	0	4	57	42	12	69	40	81	123	239	776	386	526	950
		21	21	26	83	125	137	206	238	351	444	683	1459	1845	2369	3319
3	Mexico		2	1	0	0	0	0	1	0	0	0	83	0	0	317
		0	2	3	3	2	2	2	3	3	3	3	86	86	85	402
4	Costa	20	0	3	7	20	0	0	0	0	0	1	3	0	0	49
	Rica	20	20	23	30	50	50	50	70	70	70	71	74	74	74	123
5	Cuba													2	5	0
														2	7	7
6	Jamaica	0.2	0	0	0	0	0	0	0	0	21	0	0	0	0	9
		0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	21	21	21	21	21	30
7	Caribbean										22	0	0	0	0	12
	(Rother)									15	37	35	35	35	35	47
8	Argentina	2	0	8	3	0	0	10	4	0	0	0	0	0	2	0
		2	2	10	13	13	13	23	28	28	28	28	29	29	31	31
9	Brazil			3	14	8	0	0	0	9	0	0	208	10	94	261
			3	3	17	25	20	20	20	29	29	29	237	247	339	600
10	Chile									1	0	0	0	18	0	58
									1	2	2	2	2	20	20	78
11	Ecuador													3	1	0
													0	3	4	4
12	Gujina										10	3.5	0	0	0	0
										0	10	13.5	13.5	13.5	13.5	13.5
13	Colombia										20	0	0	0	0	0
										0	20	20	20	20	20	20
14	Peru								0	0	0	0	0	0	0	0
								0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
15	Uruguay									0	0	0	0	0.4	20	0
									0.2	0.2	0.2	0.2	0.2	0.6	20.5	20
	TOTAL:	63	26	48	611	394	42	1829	455	1778	566	2675	3524	5663	9006	11,578
		1813	1725	1676	2287	2680	2717	4547	5046	6860	7405	10,087	13,580	19,276	28,210	39,854

Table 4
Wind energy in Australia and Oceania.

No.	New power Total	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
1	Australia	0	0	1	13	0	14	8	32	95	182	328	109	7	482	383
		3	3	4	17	18	32	73	103	198	380	708	817	824	1306	1877
2	New Zealand		4	0	1	30	0	0	0	20	132	0	3	151	4	172
		0	4	4	5	35	35	35	35	36	168	168	172	322	325	427
3	Pacific Islands (other)			0	1	5	0	0	0	0	0	0	6	1	0	0
			4	4	4	5	5	5	5	5	5	5	11	12	12	12
	TOTAL	0	4	1	15	35	14	8	32	115	314	328	118	159	486	555
		3	11	12	26	58	72	113	143	239	553	881	1000	1158	1643	2316

Table 5
Wind energy in Asia.

No.	New power Total	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
1	China		41	67	54	61	55	90	68	98	198	498	1334	3287	6300	13,800
		38	79	146	200	261	316	406	474	571	769	1264	2588	5875	12,210	26,010
2	India	390	240	120	82	40	76	318	195	423	875	1386	1840	1617	1800	1338
		576	816	940	1022	1062	1138	1456	1651	2125	3000	4388	6228	7845	9645	10,925
3	Japan	0	0	12	22	28	57	232	58	275	230	168	298	229	346	176
		6	6	18	40	68	125	357	415	761	991	1159	1457	1681	1880	2056
4	Taiwan						3	2	4	0	4	90	84	100	81	78
							3	5	9	9	13	104	187	280	358	436
5	South									5	47	29	75	18	43	86
	Korea								16	21	69	98	173	193	236	364
6	Philippines										0.2	25	0	0	8	8
								0	0	0	0.2	25	25	25	33	33
7	Indonesia										0.5	0.3	0	0.2	0.2	0.2
										0	0.5	0.8	0.8	1	1.2	1.4
8	Thailand										0.7	0	0	0	0	0
											0.7	0.7	0.7	0.7	0.7	0.7
9	Iran	0	3	1	4	2	0	0	1	0	6	6	27	19	17	0
		1	4	5	9	11	11	11	12	12	17	23	48	67	85	85
10	Mongolia														2	0
														0	2	2
11	Pakistan														6	0
														0	6	6
12	Israel			0	0	0	0	0	0	0	0	0	0	0	0	0
			6	6	6	6	6	6	6	6	6	6	6	6	6	6
13	Jordan			0	0	0	0	0	0	1	0	0	0	0	0	0
			1	1	1	1	1	1	1	2	2	2	2	2	2	2
14	Syria													0	0.4	0.2
											0	0	0	0	0.4	0.6
15	Turkey				9	0	10	0	0	0	1	0	31	97	286	343
				0	9	9	19	19	19	19	20	20	51	147	433	801
16	Vietnam													0	1.3	7.5
														0	1.3	8.8
	TOTAL	390	284	200	171	131	201	652	326	802	1362	2202	3689	5373	8889	15,837
		621	912	1116	1287	1418	1619	2261	2603	3526	4888	7091	10,767	16,129	24,904	40,738

3.5. Asia

Asian continent has favorable conditions for wind energy development, but they are strongly differentiated in its area owing to population density and accessibility (mountains, tropical forests, and deserts).

Due to the rapid economic development of Asian, energy needs also grows. World energy consumption has increased since 1995 from 11.5 PWh to 16.4 PWh in 2006 (42.6%). In Asia, however, this increase amounted from 3.2 PWh to 6.1 PWh.

Professional development of wind energy in Asia was initiated in India. In the early eighties the government initiated programs to develop new technologies. The installed capacity of wind power in India stood at 10.9 GW on 31/12/2009. Second country, which began intensive development of this branch of power, is China. In 2008 China reached the status of leader in Asia with installed capacity of over 12 GW. Through the new installations in 2009 with a capacity of 13.8 GW, the country was on the second position in the world, after U.S., which testifies to the high dynamics of development.

Both Asian leaders have also promoted the development of domestic wind power industry. Companies like Sinovel and Goldwind (China) and Suzlon (India) are reckoned to main players on the worlds market of wind energy equipment.

The next important region for wind energy development in Asia is Pacific region, including countries like Japan, South Korea, Taiwan and Philippines. The total power of wind turbines operating in these countries in 2009 was 2.9 GW, representing approximately 7% of the total power across the continent. Equally important is the area of the Middle and Far East covering countries from Turkey to Saudi Arabia and Iran. The leader here is Turkey with 801 MW installed capacity, far ahead of the next Iran (85 MW). It is assumed that their example would influence other countries in the region that are beginning develop wind energy utilization. However, one should note that due to the excellent climatic conditions, there is a strong competitive energy from photovoltaic cells. This technology is developing very dynamically and is particularly promoted by the countries of the Arabian Peninsula.

In 2009 Asian wind market recorded a robust growth. The new installed capacity of 15.8 GW accounted for more than 40% of the worlds, providing leadership status in Asia. At the forefront of the continent is still China, as in previous year, which doubled the size of power in wind energy. The Chinese government announced to develop wind energy to sustain economic growth of the country, so the high growth trend in this country is supposed to be continued.

3.6. Europe

Prototypes of modern wind turbines were made in Europe in the early 50s. However, the development of wind power occurred in the 70s after oil crises. Then the countries dependent on oil import started researches of new energy technologies. This resulted in modern constructions, which were the basis for further development. The leader of that studies and subsequent implementations was Denmark. Installed capacity of wind power in Denmark was 1 MW in 1980. But ten years later it was 343 MW. This rapid growth was accompanied by intensive development of wind energy industry, making Danish companies important players in the global market of wind energy equipment. In 1995 Danish manufacturer Nordex erected prototype of 1.5 MW turbine in Denmark. Vestas and German company Tacke soon followed this path. In 1995 Germany's installed capacity reached more than 800 MW

Table 6
Wind energy in Europe.

No.	New power Total	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
1	Austria	0	3	17	10	12	37	16	44	276	192	218	146	20	14	0
		3	3	20	30	42	79	95	139	415	607	820	966	982	995	995
2	Belarus	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
		0	0	0	0	0	0	0	0	0	1	1	1	1	1	1
3	Belgium	0	7	0	1	1	4	18	13	24	28	71	26	93	104	149
		7	7	7	8	9	13	31	44	68	96	167	193	287	384	563
4	Bulgaria	0	0	0	0	0	0	0	0	0	1	9	22	36	101	57
		0	0	0	0	0	0	0	0	0	1	10	32	70	158	177
5	Croatia	0	0	0	0	0	0	0	0	0	0	6	11	0	1	10
		0	0	0	0	0	0	0	0	0	0	6	17	17	18	28
6	Cyprus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		0	0	0	0	0	0	0	2	2	0	0	0	0	0	0
7	Czech Republic	0	0	0	0	0	0	0	0	7	7	9	22	64	34	44
		4	4	4	4	4	4	4	3	10	17	28	50	116	150	192
8	Denmark	150	220	259	334	306	608	170	346	235	9	22	11	3	77	334
		637	857	1116	1450	1756	2364	2534	2880	3115	3124	3128	3136	3125	3180	3465
9	Estonia	0	0	0	0	0	0	1	1	1	3	26	0	26	20	64
		0	0	0	0	0	0	1	2	3	6	32	32	58	78	142
10	Faroe	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0
	Islands	0	0	0	0	0	0	0	0	0	0	0	4	4	4	4
11	Finland	5	2	4	5	21	0	1	2	11	30	6	4	24	33	4
		6	8	12	17	38	38	39	41	52	82	82	86	110	143	146
12	France	3	7	0	9	3	40	54	0	137	138	389	810	888	950	1088
		3	10	10	19	22	62	116	116	253	391	757	1567	2454	3404	4492
13	Germany	807	413	535	794	1569	1670	2641	3247	2608	2037	1808	2233	1667	1665	1917
		1132	1545	2080	2874	4443	6113	8754	12,001	14,609	16,646	18,415	20,622	22,247	23,903	25,777
14	Greece	2	1	0	10	43	144	73	0	81	90	118	172	125	114	102
		28	29	29	39	82	226	294	294	375	465	573	746	871	985	1087
15	Hungary	0	0	0	0	0	0	1	1	0	1	14	43	4	62	74
		0	0	0	0	0	0	1	2	2	3	17	61	65	127	201
16	Ireland	5	4	40	12	10	56	0	12	54	148	159	250	59	208	233
		8	11	51	63	73	129	125	137	191	339	465	745	805	1002	1260
17	Italy	18	38	29	80	103	144	270	88	119	221	452	417	603	1010	1114
		33	71	100	180	283	427	697	785	904	1125	1718	2123	2726	3736	4850
18	Latvia	0	0	0	0	0	0	0	22	0	2	1	0	0	0	2
		1	1	1	0	0	0	2	24	24	26	27	27	27	27	28
19	Lithuania	0	0	0	0	0	0	0	0	2	5	0	49	7	3	37
		0	0	0	0	0	0	0	0	2	7	7	55	50	54	91
20	Luxembourg	0	2	0	3	5	2	0	0	0	0	23	0	0	0	0
		0	2	2	5	10	12	12	12	12	12	35	35	35	35	35
21	Netherlands	117	50	26	38	48	38	34	205	222	197	154	356	210	500	39
		249	299	325	363	411	449	483	688	910	1107	1219	1560	1746	2225	2229
22	Norway	1	4	0	5	4	0	4	80	4	59	117	47	8	102	2
		3	4	4	9	13	13	17	97	101	160	267	314	333	428	431
23	Poland	0	1	2	0	2	0	18	5	30	7	10	69	123	196	181
		0	1	3	3	5	5	23	28	58	65	83	152	276	472	725
24	Portugal	0	11	18	22	0	39	54	41	102	226	502	694	434	712	673
		9	20	38	60	60	99	153	194	296	522	1022	1716	2150	2862	3535
25	Romania	0	0	0	0	0	1	0	0	0	0	0	1	5	2	3
		0	0	0	0	0	1	1	1	1	1	2	3	8	10	14
26	Russia	5	0	0	0	1	1	0	0	3	0	2	0	1	0	0
		5	5	5	5	6	7	7	7	10	10	12	12	13	11	11
27	Slovakia	0	0	0	0	0	0	0	0	2	3	0	0	0	0	0
		0	0	0	0	0	0	0	0	2	5	5	5	5	3	3
28	Spain	76	116	263	322	391	1313	799	1493	1373	2065	1764	1587	3522	1609	2459
		133	249	512	834	1225	2538	3337	4830	6203	8268	10,028	11,615	15,145	16,740	19,149
29	Sweden	39	36	12	33	65	26	49	38	71	43	76	62	217	236	512
		69	105	117	150	215	241	290	328	399	442	509	572	788	1021	1560
30	Switzerland	0	2	0	1	0	0	4	0	0	4	3	0	0	2	4
		0	2	2	3	3	3	7	5	5	9	12	12	12	14	18
31	Ukraine	0	0	2	0	2	0	36	3	24	0	9	8	3	1	4
		1	1	3	3	5	5	41	44	68	68	77	85	89	90	94
32	United Kingdom	70	70	50	14	19	53	68	78	96	240	447	634	427	836	1077
		200	270	320	334	353	406	474	552	648	888	1332	1963	2389	3241	4051
	TOTAL	1298	987	1257	1693	2605	4176	4311	5719	5482	5757	6415	7678	8569	8592	10,183
		2531	3504	4761	6453	9058	13,234	17,538	23,256	28,738	34,493	40,856	48,507	57,004	65,501	75,354

and Europe's wind capacity overtaken the US for the first time. Somewhat later, the development of wind energy was launched in Germany, Holland, Spain, Italy and Great Britain. In 2009, at 75 GW installed capacity in Europe for these six countries accounted for 56 GW, i.e. 74% of all continent.

Development of wind energy in Europe was strongly supported by legal regulations. For example, in 1996 France launched "Eole 2005" program with target for up to 500 MW by 2005. In Germany Renewable Energy Sources Act (EEG) came into force in 2000. Under EEG regulations, electricity produced from renewable energy

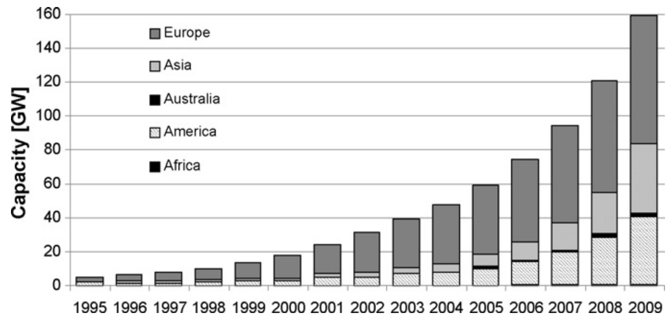


Fig. 1. The total wind energy capacity in the different continents in the years 1995–2009.

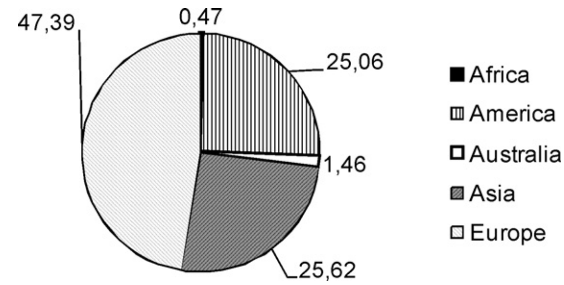


Fig. 2. Distribution of installed capacity [%] in wind power in the world (2009).

sources had priority for grid connection, grid access in either distribution and transmission grid, and power dispatch. Grid operators were obliged to feed in electricity produced from renewable sources and to buy it at a minimum price within their supply area. The law was amended in 2008, and different electricity prices were introduced depending on comparison of local wind conditions to a so-called 'reference yield'. Wind installations on very good sites receive the initial tariff for five years while turbines on less ideal sites can receive it for longer. The tariffs are paid for a maximum of 20 years.

In 2001 EU accepted a Strategy for Sustainable Development, where the reduction of emissions by an average of 20–40% by 2020 was established. It required a completely new strategy and changes in energy policies of EU countries. Decision of the Council of Europe from September 2001 stated the need for greater development of renewable energy sources: 22% of energy by 2010 in energy balance of the EU. In March 2007 the European Commission adopted energy goals by 2020. They are: the share of 20% renewable energy in the total energy production, increase of energy efficiency by 20% and reduction of CO_2 emissions by 20%.

Leader of wind power in Europe is Germany. In 2001 there were 2079 wind turbines with a capacity of 2641 MW. More than a half (53%) of new installations in 2002 in Europe was in Germany.

In 2006 in Europe there were installed over 7682 MW, of which in Germany 1158 wind turbines with a capacity of 2233 MW. A year later, in Europe, there has been installed 8285 MW, of which 3100 MW (1857 turbines) in Spain and 1667 MW in Germany (818 turbines). In 2008 out of 8592 MW for Europe, only in Germany was installed 1665 MW (866 turbines). That year wind energy recorded the biggest increase of installed capacity in relation to all other energy technologies. 8.5 GW installed in wind was more than 40% of newly total installed capacity on the continent. The largest increase recorded countries with low values of power. Hungary doubled its capacity to 127 MW, Bulgaria has tripled from 57 MW to 158 MW, and Poland almost doubled from 276 to 472 MW.

In 2009, on the mainland was installed over 10 GW of new capacity, what gave the 23% growth y/y. This value represented 39% of the new power capacity installed in Europe. Leader in this respect was Spain (almost 2.5 GW), Germany (1.9 GW), Italy, France and UK for new installations greater than 1 GW.

The first professional offshore wind farm in Europe launched in 1991 in Denmark. But offshore wind energy sector started its growth later, in the beginning of XXI century. In 2002 wind offshore capacity exceeded 200 MW, and a year later – 500 MW. With 577 MW of new capacity in 2009 it gave 54% increase y/y. In nine countries a total of 828 turbines were working in 38 farms with a total capacity of 2.056 GW. This gave average farm size of 72 MW and average size of a single turbine of 2.9 MW. The largest capacity in this segment was working in the United Kingdom (882 MW), Denmark (639 MW), Netherlands (247 MW), Sweden (163 MW), Germany (42 MW), Belgium (30 MW), Ireland (25 MW), Finland (24 MW) and Norway (2.3 MW).

The average depth at which the turbines were installed increased from 11.5 m in 2008 to 12 m in 2009. This trend was also noticed in the distance of farms from the coast: from 10.5 km (2008) to 14.4 km (2009).

On the field of wind energy in Europe now competes successfully around 45 major companies. German market is in 90% cornered by six major companies: Enercon, NEG-Micon, Nordex, Vestas, DeWind. In turn, the Spanish market a major role leads seven firms: Gamesa, EHN, Vestas, GEWind, Ecotecnia, Siemens and Nordex.

4. Global trends of wind energy development

4.1. Installed capacity

In the 90s of XX century and the first five years of XXI century, the majority of new installed capacity in wind energy was located in Europe (about two thirds of the total power) – mainly in the countries of the European Union (Fig. 1). However, recent data and projections indicate that the highest growth rates in coming years (short-term forecasts) will occur in Asian countries, as well as in the USA. However, long-term projections made for 2025 indicate that these parts will be equated and approximately 25% of the total global installed capacity will be located in Asia.

The dynamics of wind power development in the world is already high. After an initially very high growth, the percentage increase in power gradually decreases. However large absolute values are observed in the new installed power. Highest values have been listed so far in Europe. In 2008, America took the leading position (8.3 GW installed in the U.S.), and after it appeared Asia, thanks to new investment in China (6.3 GW).

In 2009 for 159 GW of wind power installed in the world, Europe accounted for 75.3 GW, i.e. nearly a half (47%). Next in order (Fig. 2) was Asia with 40.7 GW (25.6%). Asian continent noted in recent years a large increase, what with a significant wind energy potential and the growing consumption needs of the Asian countries gives the base to significant increase in the future. Reflecting this is the forecast of wind energy development providing wind power to achieve approximately 240 GW in 2011 and 290 GW in 2012 [26–32].

During analyzed period in the world there were noticed substantial quantitative and qualitative changes in installed capacity of wind power, and in maps of its distribution. The greatest dynamics of growth characterized poorly developed markets. This resulted from the fact that even the installation of small power gave a significant percentage increase. This is particularly evident (Table 7) in the cases of Africa and Australia, where growth rates were hundreds of times.

The current state of wind energy development on various continents gives some basis for forecasting the trends of further development. The biggest opportunities facing areas with goo wind

Table 7
Ratio of wind power increase for selected periods for individual continents.

Continent	2000/1995	2005/2000	2009/2005	2009/1995
Africa	45.00	1.77	3.15	250.67
America	1.50	3.71	3.95	21.98
Australia	24.00	12.24	2.63	772.00
Asia	2.61	4.38	5.75	65.60
Europe	5.27	3.09	1.84	30.00
World	3.59	3.33	2.69	32.11

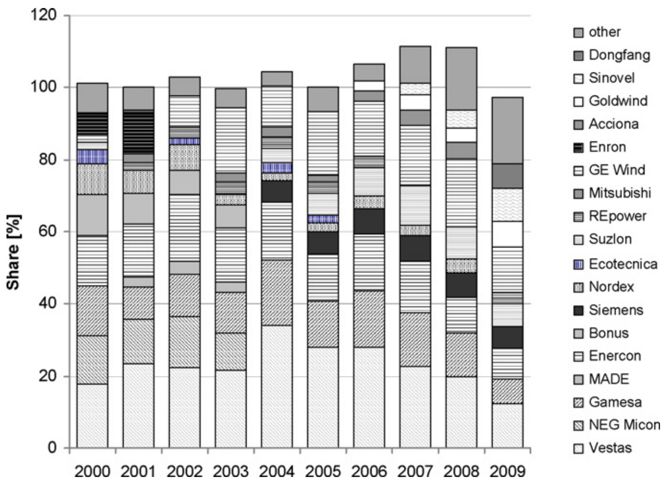


Fig. 3. The largest producers and their participation in the global market for wind power installations.

conditions and potential energy consumers, while the degree of saturation of wind power plants is low.

The global wind power market can now be divided into: mature markets – European countries (especially countries of "old" EU) and emerging markets – where the dominant is Asia.

Looking at the conditions of Europe (Table 8), it seems that the most promising is Asian market. Rising population density and low value of wind power, with the growing energy needs, provide the basis for maintaining a strong upward trend here in the next few years. A similar situation exists in the southern part of America, Eastern and Central Europe and Africa. In tropical and Saharan countries solar energy is used widely and may be more competitive because of the excellent solar conditions.

4.2. Wind energy market

On the global market currently operates many companies producing wind turbines for the professional wind energy sector. However the ten largest suppliers (the list of Top-10) cover more than 80% of the world market.

As shown in Fig. 3, in some cases the total market coverage was higher than 100%. It aroused from the fact that a greater amount of power in wind turbines was manufactured and delivered to the market than has been installed and running [9,25–32,46].

For a better understanding of the market there should be mentioned the changes in the structure of the producer [46]. Enron was bought by General Electric (GE) in 2002. NEG Micon was acquired by Vestas, and MADE by Gamesa in 2003. In 2004, Bonus Energy was bought by Siemens, in 2007 Suzlon by REpower.

Throughout the analyzed period the largest shareholder (12–34%) in the wind market was the Danish Vestas. The second group of manufacturers contains of German companies (Enercon, Nordex) and Spanish (Gamesa, Ecotecnica). The world is therefore dominated by the European wind energy industry. The majority of new installations in the world originated from Europe. Between the first ten years of analyzed period, i.e. 1995 and the end of 2004, around 76% of all new grid-connected wind turbines world-wide have been installed in Europe. This share, however, after initial growth fell to about 50% in 2006 and 27% in 2009.

In the last three years significantly increased the importance of the manufacturers from the new markets – Indian (Suzlon) and Chinese (Goldwind, Sinovel, and Dongfang). It also grows the participation of other, smaller producers outside the Top-10. Whereas in the period 2000–2006 their share was at the level of 5–8%, in 2007 it rose to 10.5% and in 2009 to 18.5%. It happens because in addition to large constructions (several MW), there is also growing number of small installations what is domain of smaller producers.

The development of wind power market creates new jobs. In Europe in companies directly and indirectly related to the wind power there was 160 thousand employees in 2008. The numbers are the highest in Germany – about 38 thousand jobs, in Denmark – about 23.5 thousand jobs, and in Spain – about 20.5 thousand jobs. EWEA expects that the sector employment will go up to 330,000 people by 2020. In comparison, the U.S. investment boom in 2008 led to the creation of 35 thousand new jobs, while the total quantity of 85,000 persons employed in the wind energy segment.

4.3. Wind turbine size

In 1995 the average size of wind turbine delivered to the market had an installed capacity of 400 kW. By the end of 2000 this figure had increased to 700 kW, and this trend is still observed.

In 2004, average capacity raised to about 1248 kW, 1400 kW in 2006 and 1599 kW in 2009. These values were different in different parts of the world. For Germany, this power was 1397 kW in 2002 and 1897 kW in 2007. In 2008 it increased by a further 26 kW to 1923 kW. By contrast, for France, the average power of the newly installed in 2005 was 1.2 MW and increased in 2008 to 1.95 MW.

Table 8
Wind power in individual continents (2009).

Continent	Installed capacity [GW]	Population [mln]	Installed wind capacity [W/person]	Area [Thous. km^2]	Wind power density [W/km^2]	Population density [persons//km^2]
Africa	0.75	973	0.77	30,317	24.80	32.09
America	39.85	914	43.60	42,500	937.75	21.51
Australia	2.32	34	68.12	7700	300.78	4.42
Asia	40.74	4054	10.05	44,600	913.40	90.90
Europe	75.35	732	102.94	10,500	7176.48	69.71
World	159.01	6707	23.71	135,617	1172.51	49.46

In 2006, the world's installed 11,127 wind turbines, of which the biggest capacity was in Europe (4591 turbines) and Asia (3655 turbines). Most (50%) of the installed turbines was with a capacity of 1501–2500 kW (about 4000 turbines with total power of 8 GW). This trend had focused on the leading countries in wind industry (Denmark, Germany, USA, Spain, United Kingdom). Turbines with capacity 750–1500 kW in 2006 accounted for approximately 43.3% (mainly in China and India). In 2007, the world's installed 14,595 wind turbines, of which the most in Asia (5231), Europe (4871) and America (4256). In 2007 most of installed turbines (47.6%) was with a capacity of 1501–2500 kW (5260 turbines with a capacity of 10,567 MW). Turbines with capacity of 750–1500 kW in 2007 accounted for approximately 45.8%. In 2009, the largest share of sales (81.8% of the total market) had the devices with the power of 1.5–2.5 MW.

The largest single installed capacity of wind power by the year 2002 was devices with the power of 2–3 MW: Nasudden II (Kvaemer Turbine) – 3 MW, Aeolus II (Kvaemer Turbine) – 3 MW, AN Bonus – 2 MW, V80 Vestas – 2 MW, Tacke TW – 2 MW, Offshore – Sudwind – 2 MW, Jacobs MD-2 MW, Micon NM – 2 MW and 2.5 MW unit Nordex N – 2.5 MW. At the end of August 2002 there was erected the largest commercial prototype turbine near Magdeburg, in eastern Germany: Enercon E-112 4.5 MW (124 m tower height).

In 2007 the biggest turbines which were available on the market are: Enercon E112 – 4.5 MW/6 MW, GEWind 2.5 – 2.5 MW, Siemens SWT3.6-107 – 3.6 MW, and Vestas V90–3 MW. In 2008 they were Enercon E-126 power 6 MW, 104 GE Wind 3.6 MW REpower 5 M – 5 MW and Multibird M5000 of 5 MW.

In 2009 Norway announced the construction of the largest wind turbine in the world with a capacity of 10 MW. A prototype of a windmill built by a Norwegian company Sway will be set to land in Oeygarden in south-western Norway in 2011, where new construction will have been studied for two years. This information confirms the trend of further development of the so-called multi-megawatts turbines with a capacity exceeding 3 MW and the development of large power plants at sea (offshore). The world's worked 18 farms on the sea with a capacity of 878 MW (417 turbines) in 2006. Two years later offshore wind power contained 1471 MW.

Unit investment outlays in 2001, i.e. the cost per kilowatt of installed capacity for wind turbine with the power above 600 kW was in a U.S. conditions 800$/kW. In 2007 in Europe it was around 1000 EUR/kW, and rose to 1260 EUR/kW in 2008 (delivery in 2009).

5. The development and current status of wind energy in Poland

5.1. Wind energy potential in Poland

Poland lies in Central Europe in the temperate climate zone. The researches of wind energy gave rise to a finding that Poland has good opportunities to develop wind energy. According to measurements and researches of Professor H. Lorenc [47,48], the technical potential of wind energy in Poland is 330 PJ/year. At about 2/3 area of Poland total annual wind energy on the surface of 1 m^2 at a height of 30 m above ground level is 750–1500 kWh/year. This implies the existence of favorable conditions for the professional development of wind energy [36,49]. But, of course, each case recommends detailed studies of the wind conditions.

Polish territory is divided to few basic areas in terms of wind energy resources (Fig. 4). Geographically, they include the following parts of the country (Table 9):

I. an area extremely beneficial, the coastal belt (Szczecin Coast, Gdansk Coast, Suwalki), middle and northern part of Wielkopolska, Mazovia,

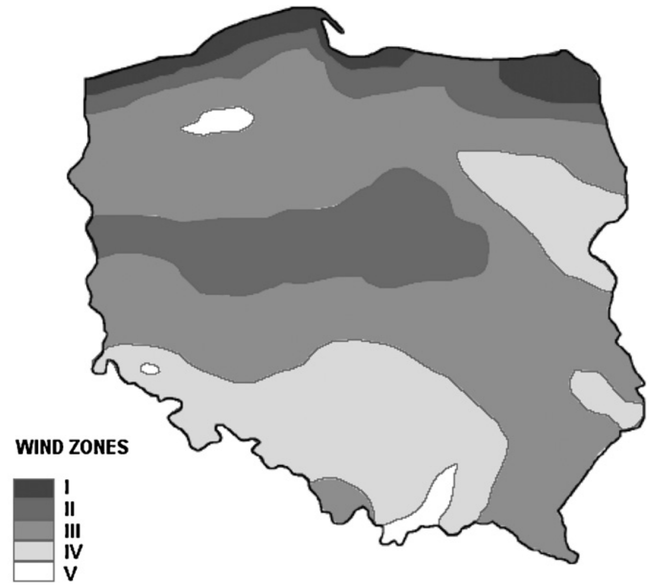


Fig. 4. Wind energy zones at an altitude of 30 m above the ground.

Table 9
Regionalization of the wind energy potential in Poland.

Zone	Wind energy density, kWh/m^2
I	>2000
II	1500–2000
III	750–1500
IV	500–750
V	<500
VI	n.a.

II. an area favorable to the middle part of the country,
III. an area quite favorable, foothills,
IV. the area adversely, the variable wind speed,
V. very negative territory, the valley with lots of calms, mountain areas, with variable wind speeds, and
VI. areas excluded from wind energy, high parts of the mountains, strong and variable winds.

The wind energy density for each wind zone in Poland at an altitude of 30 m above the ground is shown in Table 9.

5.2. Legal conditions of wind energy development

The development of wind energy in Poland is linked to a system of green certificates for renewable energy producers. Thanks to this support a number of investments in renewable sources of energy become economically viable. In 2005, based on the provisions of Directive 2001/77/EC on the promotion of electricity from renewable sources, an amendment to the Energy Law has been made. According to it, energy company engaged in the generation of electricity or its marketing and selling this energy to end-users connected to the network, is required to obtain and submit to the redemption of the President of Energy Regulatory Office (URE in Polish) certificate of origin, or pay the replacement fee. Property rights arising from certificates of origin are negotiable. Thus, the producer of electricity from RES earns revenue from two sources: the sale of the electricity and the sale of green certificates. The sale of "physical" energy is carried on by the average price for a competitive market in the year preceding the sale of energy.

In 2009, the President of URE issued 2155 green certificates for a total 1.03 TWh of electricity generated by wind power [50]. The average price of electricity from renewable energy

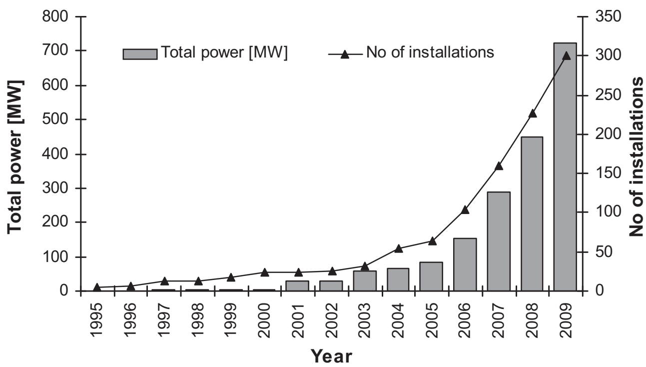


Fig. 5. Wind energy development in Poland.

sources on which the producer sold it in 2009 amounted to 155.44 PLN/MWh plus 258.89 PLN/MWh replacement fee. Therefore, the total selling price of wind electricity was on the Polish market for over 100 EUR/MWh (with a rate of 4.20 PLN/EUR). It is therefore a lot, even for conditions much wealthier western European countries. As a result, a support system for renewables causes significant interest of foreign investors in wind energy market in Poland.

5.3. Wind power installed in Poland

First professional wind turbines connected to the national grid launched in the year 1991, in Lisewo (150 kW) and in Swarzewo (95 kW). The first wind farm in Poland was established in 2001 in Barzowice. Its power accounted for 5 MW [51]. After several years of trials, uncertainties and changes in law regulations, wind power started to develop intensively since 2006. In the 2007 there were opened several wind farms with a total capacity of over 130 MW, while in the first nine months of 2008 was built 57.6 MW of new capacity. According to the Energy Regulatory Office on 31/12/2008, the total installed capacity of 227 licensed sources wind (single turbines or wind farms) in Poland amounted to 451.09 MW. Half a year later (30/06/2009) in Poland, worked 253 sources with total capacity of 553 MW. Within six months therefore, there were installed 28 new sources with a total capacity of more than 100 MW. As at 31/12/2009 in Poland, was installed 301 sources with a capacity of 724 MW. The development of wind energy in Poland from 1995 to 2009 is shown in Fig. 5.

Government plans accepted in 2005 [52,53] established 2000 MW of installed wind energy and 2.3% share of wind generation in the national energy consumption in 2010. To achieve this objective in the years 2006–2010 was needed to increase capacity by more than 1800 MW, which meant the need to connect about 450 MW/year [54]. As the pace and size of the investments have increased significantly only in the last three years, these assumptions are likely to be satisfied with delay. It should not be it, however large. Ongoing projects and disclosed plans to investors (Table 10) shows the possibility to run new plants with a capacity of over 1 GW.

Referring to [41] and taking into account current technical and technological conditions and the real level of development of wind energy by 2020 is to install and achieve 14 GW of electricity production from wind power at 30 TWh.

Location of larger wind farms in Poland, due to the information in Table 10, is shown on the map (Fig. 6).

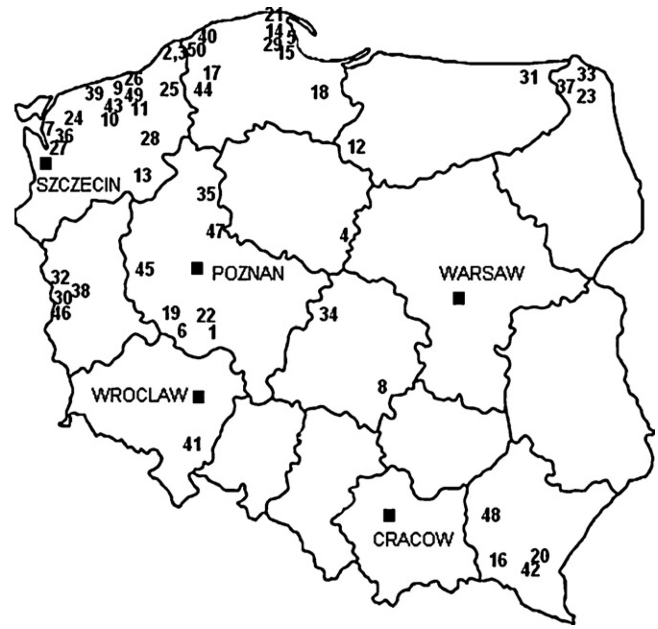


Fig. 6. Location of main wind farms in Poland. Marked boundaries of voivodeships.

5.4. Electricity from wind generation in the Polish energy system

Electricity generation in Poland is based almost exclusively on domestic coal (hard and brown). The share of coal in electricity generation is the highest among the European countries and is above 90%. The share of natural gas in electricity generation has been increasing, although it is still very low. A small percentage of electricity also comes from oil and renewable sources. Electricity generation has been increasing in recent years and is expected to increase in coming years, despite rising prices of electricity.

The increase in installed capacity of wind turbines is associated with the share of energy generation, what is presented in Table 11. The average working time of wind turbines at nominal power was approximately 1800 h/year. It is only 40% of the time recorded in the power of conventional (approximately 4600 h/year).

Such intermittent nature of wind power requires reservation of extra capacity in conventional power system. This causes additional expenditure increasing the cost of electricity produced from wind. The paper [55] for the conditions specified in 2006 stated that the unit cost of electricity generation for wind farms was calculated for 307 PLN/MWh and 345 PLN/MWh in case of additional conventional power reserve. If wind energy development requires expansion of electricity grids and that power reserve, electricity produced from wind will need to be charged these additional costs. Polish Power Grid S.A. (PSE S.A.) as a transmission system operator shall assess that at present is technically possible to connect to the system wind farms with a capacity of approximately 8 GW, but capacity of reserve sources should rise about 1.9 GW [56]. These sources would be activated in the windless weather. With the growing interest in investing in wind power, it seems that investors should pay for this reserve capacity.

The development of wind energy also inhibits the lack of developed network infrastructure in areas with good wind conditions (Fig. 7) that occur mainly in the northern and western Polish, where the power network is week. So, further increase of wind power should be associated with the expansion of HV transmission networks (mainly 110 kV and 220 kV). For obvious reasons, the main players in the market will want to avoid additional costs. There is therefore a real danger that will be reflected in an increase in energy prices for final consumers.

Table 10
Larger (>5 MW) completed, under construction and planned investments in wind energy in Poland, 31/12/2009.

	Locality	Rating power of a single turbine [MW]	No of turbines [–]	Capacity [MW]
	Completed			
1	Babkowice			7.50
2	Barzowice	0.83	6	5.00
3	Cisowo	2.00	9	18.00
4	Dobrzyń	2.00	19	38.00
5	Gnieżdżewo	2.00	11	22.00
6	Golinka	2.50	2	5.00
7	Jagniątkowo	1.80	17	30.60
8	Kamieńsk	2.00	15	30.00
9	Karcino	3.00	17	51.00
10	Karnice	2.30	13	30.00
11	Karścino	1.50	60	90.00
12	Kisielice	1.50	27	40.50
13	Krzęcin	1.50	4	6.00
14	Lisewo	0.60	18	10.80
15	Łebcz	2.00	4	8.00
16	Łęki Dukielskie	2.00	5	10.00
17	Łosino	2.00	24	48.00
18	Malbork	1.50	12	18.00
19	Nowawieś	2.50	4	10.00
20	Hnatkowice-Orzechowce	2.00	6	12.00
21	Ostrowo	1.80	17	30.60
22	Strzelce Wielkie	2.50	2	5.00
23	Suwałki	2.30	18	41.40
24	Śniatowo	2.00	16	32.00
25	Tychowo	2.50	20	50.00
26	Tymień	2.00	25	50.00
27	Zagórze	2.00	15	30.00
28	Zajączkowo and Widzino	2.00	45	90.00
	Under construction			
29	Gnieżdżewo			22.00
30	Golice			38.00
31	Gołdap			69.00
32	Górzyca	2.00	24	48.00
33	Jeleniewo			30.00
34	Kozanki Wielkie			n.a.
35	Margonin	2.00	60	120.00
36	Ostrowo	1.80	17	30.60
37	Piecki			32.00
38	Rzepin	2.00	34	68.00
39	Skrobotowo			26.00
40	Słupsk–Ustka	2.30	104	240.00
	Planned			
41	Ciepłowody	2.00	20	40.00
42	Husów -Tarnawka	2.50	18	45.00
43	Jarogniew-Mołtowo			20.00
44	Kończewo		11	43.00
45	Kuślin		34	>70.00
46	Golice	2.00	19	38.00
47	Mieleszyn	2.50	48	120.00
48	Padew Narodowa	2.00	20	40.00
49	Parnowo	1.50	9	12.50
50	Ustka	2.00	13	26.00

Table 11
Wind energy generation vs. thermal power stations in Poland [41,50].

Year, -	Production of electricity from wind power, GWh	The share of wind generation in the national electricity consumption, %	Wind power plants – the average working time (nominal power), h/year	National electricity consumption, TWh	Electricity plants – the average working time (nominal power), h/year
2000	5.4	0.004	1038	138.8	4527
2001	14.0	0.010	1305	138.9	4467
2002	61.0	0.045	2107	137.0	4450
2003	124.0	0.088	2018	141.5	4616
2004	142.3	0.098	2014	144.9	4678
2005	135.3	0.093	1625	145.7	4840
2006	388.4	0.258	2551	150.7	4888
2007	494.2	0.322	1717	153.7	4903
2008	790.2	0.511	1752	154.7	4772
2009	1029.0	0.692	1420	148.7	4674

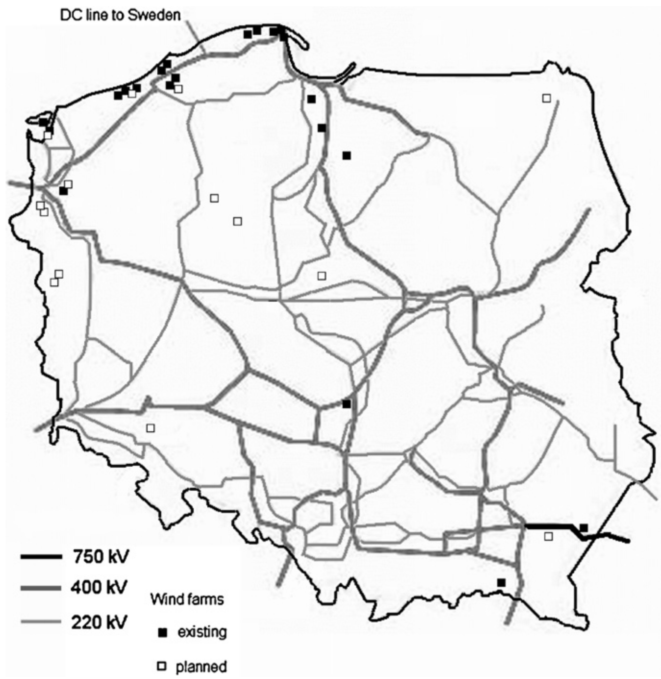


Fig. 7. Polish electric power system and distribution of larger (>5 MW) wind farms in Poland.

In addition, a system of connection terms for wind sources caused that a large number of issued permits for a long time was not active, what blocked the execution of projects ready for implementation. To limit these practices from 2010 was introduced the additional fee (currently 30,000 PLN/MW), collected from investors at the stage of applying the terms of the network connection. This allowed to acquirie additional funds for the construction of new networks. Investors are motivated for quick action and implementation of new installations.

On the Polish wind energy market dominant share have European companies. For example, by the end of the first half of 2007 in the farms with a capacity greater than 5 MW the largest share had Vestas (52.8%), GE Wind Energy (23.2%), Enercon (15.3%) and Gamesa (8.7%).

Currently it is estimated [41] that the national market for over 100 is involved in the preparation of wind projects or acquisition of land for wind investments. Employment in the sector of wind energy in Poland is currently around 1200 people. Most jobs are created in companies involved in carrying out projects to build wind farms.

In addition to large investors in the wind power market there are also small entities, and also individuals. In the late 1990s thanks state funds and Nowomag company was built a prototype and the subsequently construction of professional wind turbines of 160 kW. However, because of the absence of policy to support renewable energy and bureaucratic barriers increasing investment costs, although a sizeable investor interest, the production and further development was stopped. Now, because of a total lack of interest in research on the development of the national construction of wind power, small domestic investors use imported devices in the so-called repowering. This trend has intensified from about 2003 and still maintains. Most devices are imported from Germany, the Netherlands and Denmark. Their average power is mainly in range from 150 kW to 800 kW.

6. Conclusions

Wind energy is a very fast growing part of the electricity generation in the world. In Polish conditions social acceptance of renewable energy sources (RES) is large, although for wind energy is smaller. This is mainly due to interference and noise in the vicinity of such facilities. Generally, however, it should be noted that in Poland there is a positive climate for investment in renewable energy sources. However, investments in wind power face several obstacles, the most important are:

- Lack of clear rules for cost sharing connection between the operator and the entity connected to the network,
- Lack of investment allocation of small (some tens of kW) and large, which causes inconvenience and high costs for small investors.
- Lack of a developed transport infrastructure in areas with good wind conditions,
- Lack of legal opportunities for rapid implementation of network investment,

Despite these barriers the attitudes of communities are gradually changing, initially very wary of wind power, particularly ornithologists. In addition, electricity consumers can see wind turbines operating in a country, which is also important in "green education".

In Polish conditions one should note technical limitations occurring in the electricity transmission system. Linked to this is the need for new network investment, which should be an important factor in developing the wind energy in Poland. Wind energy also needs reserve power. In Poland thermal power plants are concentrated in the southern part of the country. Their long distance from the wind turbines located mainly in the northern part of the country increases the cost of transmission and a significant decline in the competitiveness of wind energy.

Disclosure statement

We see no reason to set out the potential conflicts caused by the article that could inappropriately influence our work. We do not have links through employment, consultancy, stock ownership, honoraria, paid expert opinion, patent applications and grants or other funding from individuals and organizations associated with the described subject of wind energy.

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